Engineering Design File

Project No: 22901

Evaluation of Necessity of Off-Gas Scrubber for V-Tanks Treatment Process

Idaho Cleanup Project

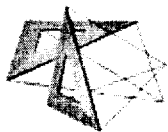The Idaho Cleanup Project is operated for the
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EDF No.: __5905__   EDF Rev. No.: __0__   Project File No.: __22901__

1. Title:	EVALUATION OF NECESSITY OF OFF-GAS SCRUBBER FOR V-TANKS TREATMENT PROCESS

2. Index Codes:

Building/Type __WAG 1__   SSC ID __N/A__   Site Area __TAN__

3. NPH Performance Category: _____ or ☒ N/A

4. EDF Safety Category: _____ or ☒ N/A   SCC Safety Category: __N/A__ or ☒ N/A

5. Summary: The option of not using the venture/packed bed scrubber on the V-Tank Project consolidation tank sparging off-gas treatment was evaluated. In lieu of the scrubber, in-line vent demisters would be installed. However, the radiation fields background and on the HEPA filter, are still low. It is recommended to use the in-line demisters. Also, no additional isolation for the HEPA filters is required. This assessment is limited in application to sparging and consolidation type operations. If chemical oxidation or boiling conditions are deployed as part of the conditional Phase 2 operations then the necessity of the scrubber should be revisited.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	R/A	Typed Name/Organization	Signature	Date
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Reviewer	R	R. Sorensen	*R. Sorensen*, via e-mail	06/09/05
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Doc. Control				

7. Distribution: (Name and Mail Stop)	S.C.Ashworth 3670, M.E. Bodily 3650, D.F. Nickelson 3670, D.L. Eaton, D.R. Tyson 9206, J.J. Jessmore 9206, R. Sorensen 9208

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06/09/2005 05:00 PM

To Roger D Orme/RO2/CC01/INEEL/US@INEL

cc David F Nickelson/DFN/CC01/INEEL/US@INEL

bcc

Subject Fw: EDF-5905

You also have Rick Sorenson consent to sign per email. Looks like he made the mistake I did and replied to Sam thinking that you were on the cc list.
Oh well. Have a great weekend.
Dave

David L. Eaton
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Rick Sorensen/DSOR/CC01/INEEL/US
06/09/2005 01:30 PM

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cc David L Eaton/DLE/CC01/INEEL/US@INEL, David R Tyson/TRD/CC01/INEEL/US@INEL, Mark E Bodily/MEB2/CC01/INEEL/US@INEL

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Sign me up per this email.

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Samuel C Ashworth/ASHWS/CC01/INEEL/US
06/09/2005 12:45 PM

To Mark E Bodily/MEB2/CC01/INEEL/US@INEL, David L Eaton/DLE/CC01/INEEL/US@INEL, Rick Sorensen/DSOR/CC01/INEEL/US@INEL, David R Tyson/TRD/CC01/INEEL/US@INEL

cc

Subject Fw: EDF-5905

----- Forwarded by Samuel C Ashworth/ASHWS/CC01/INEEL/US on 06/09/2005 12:44 PM -----

Roger D Orme/RO2/CC01/INEEL/US

To David F Nickelson/DFN/CC01/INEEL/US@INEL

Samuel C
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EL/US
05/09/2005 03:25 PM

To   Roger D Orme/RO2/CC01/INEEL/US@INEL
cc
bcc
Subject   Fw: EDF_558

Dave Tyson has a few minor ones (EU1)

----- Forwarded by Samuel C Ashworth/ASHWS/CC01/INEEL/US on 05/09/2005 03:24 PM -----

David R
Tyson/TRD/CC01/INEEL/US
05/09/2005 02:37 PM

To   Samuel C Ashworth/ASHWS/CC01/INEEL/US@INEL
cc
Subject   EDF_558

Sam: I have 2 small comments. Once corrected, you can copy this note to Roger as my approval.
---Dave

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Dave Tyson, Ph.D.
Advisory Engineer - Chemical Engineer
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trd@inel.gov

David F Nickelson/DFN/CC01/INEEL/US
05/10/2005 07:57 AM

To Samuel C Ashworth/ASHWS/CC01/INEEL/US@INEL, Roger D Orme/RO2/CC01/INEEL/US@INEL
cc
bcc
Subject Re: Fw: EDF-5558

I approve.

thanks

Samuel C Ashworth/ASHWS/CC01/INEEL/US

Samuel C Ashworth/ASHWS/CC01/INEEL/US
05/10/2005 07:29 AM

To C Jestin Hurst/HURSCJ/CC01/INEEL/US@INEL, David F Nickelson/DFN/CC01/INEEL/US@INEL
cc
Subject Fw: EDF-5558

----- Forwarded by Samuel C Ashworth/ASHWS/CC01/INEEL/US on 05/10/2005 07:28 AM -----

Roger D Orme/RO2/CC01/INEEL/US
05/10/2005 07:27 AM

To Samuel C Ashworth/ASHWS/CC01/INEEL/US@INEL
cc
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Tyson comments are in. We only need Nickelson and Hurst signatures.
Samuel C Ashworth/ASHWS/CC01/INEEL/US

Samuel C Ashworth/ASHWS/CC01/INEEL/US
05/09/2005 03:25 PM

To Roger D Orme/RO2/CC01/INEEL/US@INEL
cc
Subject Fw: EDF_558

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Dave Tyson, Ph.D.
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To   Roger D Orme/RO2/CC01/INEEL/US@INEL

cc

bcc

Subject   Fw: EDF-5905

Roger,
I must have missed your name in the note below. As noted below, you can sign for me per this email.
Dave

David L. Eaton
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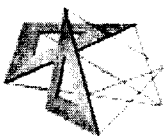
David L
Eaton/DLE/CC01/INEEL/US
06/09/2005 12:49 PM

To   Samuel C Ashworth/ASHWS/CC01/INEEL/US

cc   David R Tyson/TRD/CC01/INEEL/US@INEL, Mark E
Bodily/MEB2/CC01/INEEL/US@INEL, Rick
Sorensen/DSOR/CC01/INEEL/US@INEL

Subject   Re: Fw: EDF-5905

You can either sign for me per this email or we can fax signed signature page to you.
Dave

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Samuel C Ashworth/ASHWS/CC01/INEEL/US

Samuel C
Ashworth/ASHWS/CC01/INE
EL/US
06/09/2005 12:45 PM

To   Mark E Bodily/MEB2/CC01/INEEL/US@INEL, David L
Eaton/DLE/CC01/INEEL/US@INEL, Rick
Sorensen/DSOR/CC01/INEEL/US@INEL, David R
Tyson/TRD/CC01/INEEL/US@INEL

cc

Subject   Fw: EDF-5905

----- Forwarded by Samuel C Ashworth/ASHWS/CC01/INEEL/US on 06/09/2005 12:44 PM -----

Roger D
Orme/RO2/CC01/INEEL/US

To   David F Nickelson/DFN/CC01/INEEL/US@INEL

To   Roger D Orme/RO2/CC01/INEEL/US@INEL

cc

bcc

Subject   Re: 5905

By virtue of this email I approve EDF-5905. Please sign for me.
Thanks
Mark Bodily

Roger D Orme/RO2/CC01/INEEL/US

**Roger D
Orme/RO2/CC01/INEEL/US**

06/09/2005 04:11 PM

INL
Idaho National
Laboratory

To   Mark E Bodily/MEB2/CC01/INEEL/US@INEL

cc

Subject   5905

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2. Index Codes:

Building/Type __WAG 1__   SSC ID _N/A_   Site Area _TAN_

13. Registered Professional Engineer's Stamp (if required)

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ACRONYMS

AEA   AEA Technologies

HEPA   High efficieny particulate air (filter)

TAN   Test Area North

VOC   Volatile organic compound

NOMENCLATURE[a]

a   Specific surface area, ft^2/ft^3

A   Area, ft^2

Arch   Archimedes Number

ARF   Airborne release fraction, kg droplets in vapor/kg liquid poured

C   Total concentration, nCi/g

Ci   Curie, 3.7×10^{10} dis/s

d   Fraction particles deposited (prior to release)

D   Diameter, ft

DF   Decontamination factor

eV   Electron-volt, Coulomb-volt

E   Entrainment, mass velocity of droplets/mass velocity air

E_γ γ Photon energy, MeV

f_m Particle bed friction factor

g   Gravity acceleration, L/t^2

G   Mass velocity, $lb/ft^2/hr$

H   Dose rate, mRad/hr

K_m Separation number coefficient

L   Loading, Ci/kg/s, length, ft

m   Equipment concentration, Ci/kg

---

[a] Any consistent set of units except for dimensional equations

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MW	Molecular weight, g/mol
n	Pressure loss parameter
n_s	Separation number
ppm_v	Parts per million, volume basis
P	Radionuclide particle power/unit mass, J/kg/s, pressure
Q	Flow, ft^3/min or gpm, quality factor
r	Rate, nCi/min
Rad	100 erg/g
Re	Reynolds number
R_g	Gas constant, L-atm/mol/°K
t	Time, t
T	Temperature, °K
v	Velocity, ft/s
V	Volume, ft^3
W	Weight, kg
y	Gas concentration, Ci/L
z	Height, ft

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ε	Void fraction
η	Efficiency
λ	Droplet mean free path, μm
μ	Viscosity, lbm/ft/s
μm	Micro meter (micron)
φ	Shape factor
ρ	Density, kg/L

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1.   INTRODUCTION

1.1   Background

The Test Area North (TAN) V-Tanks project provided a design for air stripping volatile organic compounds (VOCs) from the waste solutions in the V-Tanks. The design was based on transferring the V-Tank contents to consolidation tanks followed by air-stripping (sparging) using specially designed consolidation tank features as discussed in a previous EDF-4956 (Ashworth 2004). At the time, a post-sparging Fenton process by AEA Technologies (AEA) was planned that required a venturi-packed bed scrubber system (Severn-Trent). The project direction was to flow the sparge air and Fenton off-gas through the scrubber process prior to treatment by other off-gas components (e.g., HEPA and GAC). Since then, approval was given to conduct initial operations, such as sparge only and not operate the Fenton process (DOE 2005). Some of the options for scrubber operation were discussed in EDF-4956 per project request. It was found that the scrubber could either be bypassed or operated with modifications. In lieu of the scrubber, it is recommended that a demister unit would be utilized prior to the HEPA and GAC bed.

If Phase 2 treatment operations are determined to be necessary which employ either chemical oxidation and/or boiling conditions, then the necessity of the scrubber to control radioactive off-gas emissions should be revisited.

2.   Scope

This EDF is to provide a basis for bypassing the scrubber in the system and replacing it with a demister. In addition, it provides a basis for not installing isolation valves around the HEPA.

3.   SAFETY CATEGORY

Consumer Grade.

4.   NATURAL HAZARDS PHENOMENA PERFORMANCE CATEGORY

N/A

5.   SUBJECT-SPECIFIC DATA

The Appendix B provides for approximate radiation fields as a result of replacing the scrubber with in-line demisters and includes most of the analysis. Per the scope, this EDF addresses the following three issues:

5.1   Scrubber Requirement

The reason for the scrubber was to remove particles with a high degree of efficiency from vapors emitted by the Fenton process, operated at or near the boiling point. It is not clear from their basis but the vendors apparently assumed a large entrainment from the process. The basis is not documented. They also used a removal efficiency of 99.99% for particles in their vendor data. While it is believed that units like this would be desirable for off-gas systems used in treating highly radioactive solutions to reduce the radiation fields in downstream HEPAs, they are usually not specified for low level wastes such as the

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V-Tanks. Much of this is based on experience but it can also be documented as in the radiation field calculations provided in Appendix B. The scrubber system for processing the V-tank waste is not required based on the estimates in Appendix B and the fact that the boiling conditions or Fenton-type reaction system will not be used in this phase of treatment operations.

5.2 In-Line Demister

Although a scrubber is not required, a demister to reduce HEPA loading and radiation fields is prudent. Appendix B shows how this impacts the radiation fields. There is a minor increase in background levels[b] and around the HEPA filter (Briggs et al.). However, fields are reasonable per conservative estimates. The demister needs to remove at least 99% of the mists/particles. This can be done by using the specified (Appendix B) demister material. The mesh material was chosen based on its known properties, i.e., $\Delta P = 0.2 - 0.4$ in H_2O for a 12-inch section and effective for 5 μm particles/mists. The demister suggested is a slip-in, wire mesh unit shown in Figure 1. As shown, the bottom of the mesh would be approximately flush with the tank top to promote good drainage although vendor supplied proprietary data indicate it could probably go in any position. The rough HEPA estimate discussed in Appendix B is 0.83 mR/hr for 68 days of continuous sparging and re-circulation. This was somewhat refined by using Microshield 0.15 – 0.21 mR/hr (Sorensen 2005).
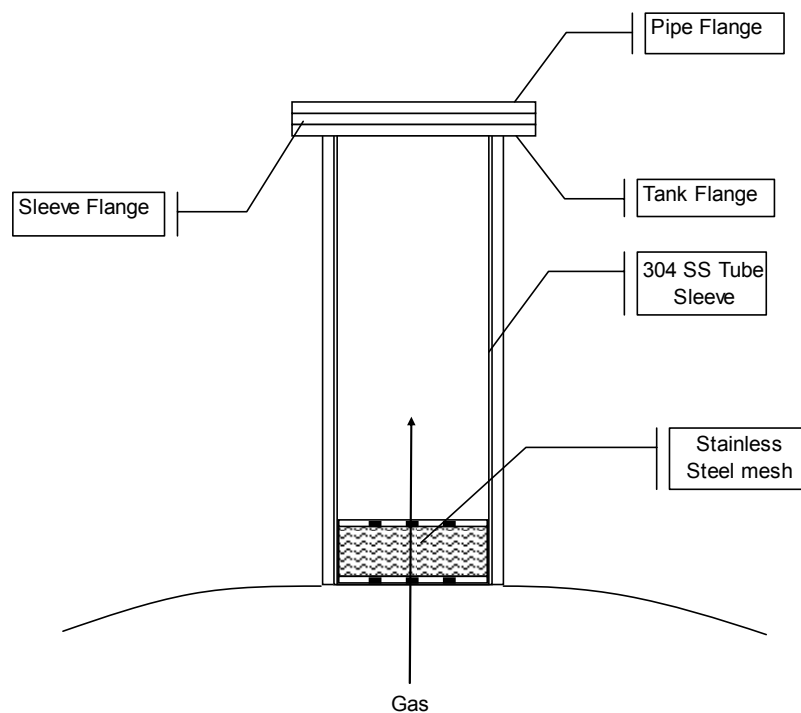

Figure 1. Demister Schematic

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[b] An estimated background increase of < 1% at point of discharge by substituting an in-line demister.

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5.3   HEPA Isolation

Due to low radiation fields predicted from use of an upstream demister, the currently available, upstream valves are sufficient to isolate the HEPA in the unexpected event of a changeout. Air-sparging and active off gas system operations will need to suspended during HEPA changeout which is acceptable from a process/technical and functional requirements perspective since the solids can be re-suspended by re-circulation pumping and the agitator.

6.   ASSUMPTIONS

- There are two major entrainment mechanisms included, one via air sparging (40 cfm of air) and the other via splashing from re-circulation liquid (100 gpm of re-circulating liquid introduced at a height of three feet above the tank liquid).

- The entrained aerosols/mists have a particle distribution that 95% > 5μm by mass. This is uncertain as the distribution was not determined.

- Others as stated in calculations (Appendix B).

7.   ACCEPTANCE CRITERIA

The change in design (a custom in-line demister to replace the current scrubber) leads to acceptable radiation fields and is protective of the HEPA filter.

8.   SOFTWARE

The following industry-wide software, requiring no validation, was used for this EDF:

- MathCad Version 11.

- EXCEL Version 2003.

9.   CALCULATIONS

See Appendix B.

10. CONCLUSIONS

In general, by replacing the current scrubber with a custom in-line demister, the background levels at the stack point of discharge may increase (<1% estimated). The radiation field at the HEPA surface is expected to increase slightly but still meet ALARA goals. The HEPA filter is protected from particles and mists greater than 5 μm in diameter and most of those less than 5 μm. The HEPA does not require additional isolation for change-out. While it is possible to fabricate a demister mesh, a vendor specified mesh/packing is preferred to minimize pressure loss while obtaining the needed efficiency, i.e., the media specified in Appendix B has known pressure loss and efficiency. No additional HEPA isolation is required.

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11. RECOMMENDATIONS

It is recommended to use an in-line demister if the scrubber is not used. This demister should be a vendor supplied mesh/packing as discussed in Appendix B and welded or otherwise attached to the bottom of a sleeve or tube inside the flanged vent penetration as shown in Figure 1. Appendix B provides a specification. Provide no additional HEPA isolation than that already provided by the upstream valves. If Phase 2 treatment operations are determined to be necessary at elevated temperatures or using the Fenton reaction, then the requirement for the scrubber should be reevaluated.

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Appendix A – Task Planning Documentation

Add on TBA for Project 22901

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Appendix B – Calculations

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Appendix B, Supporting Calculations

Contents
I.   **Data**
II.   **Characterization**
III.   **Entrained Radionuclides and Loadings**
IV.   **Demister Mesh Design**

I. Data. The data below are used in the Estimates

$$P := \frac{12.5}{14.7} atm \qquad\qquad T_g := 298K \qquad\qquad R_g := 0.082\frac{L \cdot atm}{mol \cdot K}$$

$$\rho_{H2O} := 1\frac{kg}{L} \qquad\qquad MW_{air} := 29\frac{gm}{mol}$$

$$Q_s := 40\frac{ft^3}{min} \qquad\qquad \text{Sparge nominal rate and time} \qquad t_s := 42 \ hr$$

$$D_{tk} := 10ft \qquad\qquad A_{tk} := \frac{\pi}{4} \cdot D_{tk}^2$$

Liquid viscosity, the factor of 2 is to account for solids   Vapor viscosity (both viscosities from Kreith, Kreith 1973)

$$\mu_L := 0.658 \ 10^{-3} \frac{lb}{ft \cdot s} \cdot 2 \qquad\qquad \mu_g := 1.2 \cdot 10^{-5} \frac{lb}{ft \cdot s}$$

Vapor and liquid densities (assume 1 for liquid because of the uncertainties in other data).

$$\rho_g := \frac{P \cdot MW_{air}}{R_g \cdot T_g} \qquad\qquad\qquad \rho_L := 1\frac{kg}{L}$$

The tank vapor, superficial velocity: $v_{tk} := \frac{Q_s}{A_{tk}}$

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Derived Units/Miscellaneous

$$Ci := 3.7 \cdot 10^{10} s^{-1}$$ Curie definition/nano-Curie $$nCi := 10^{-9} Ci$$ $$ppm_V := \frac{atm}{atm} \cdot 10^{-6}$$

$$eV := 1.60219 \cdot 10^{-19} coul \cdot V$$ $$MeV := 10^{6} \cdot eV$$ $$keV := 10^{3} eV$$ $$Rad := 100 \frac{erg}{gm}$$

$$mRad := 10^{-3} Rad$$ $$\mu m := 10^{-6} m$$

II. Characterization

To determine the applicable VOCs, data from two characterization reports (Tyson 2003, Tyson 2004) were used. However, these data needed to be filtered. The prescription used was to retain any component that had a detected concentration. For the V-tanks, this prescription was applicable for any tank in either phase. This was done at the 95% confidence level with the detect values used for any of the wastes where at least one detect value was listed (i.e., for the V-tanks, if one tank had an actual number where one or more of the other tanks had detect values, the detect values were averaged together with the actual numbers). This was done at the 95% confidence level using the Microsoft Excel function   TINV(probability, degrees of freedom).

$$C_i(95\%) = C_i + TINV(\Psi, df) \cdot \varepsilon_s$$

For the 2-tailed probability: $$\psi = 0.1$$

The standard error, ε_s, and the degrees of freedom, df, were taken from the characterization reports (Tyson 2003 and Tyson 2004), where the second report accounts for the miscellaneous effluents that will be added. In general, the addition of these waste streams have a minor impact on the original characterization of the V-tanks, except for the additional TCA from ARA-16 that is approximately 25,000 mg/kg in the sludge. The report discussing these waste streams (Tyson 2004) provides weight-averages for the various detected constituents. Basically, the method follows:

1.   Individual averages, standard errors, and degrees of freedoms were calculated for both sludge and liquid in all four V-tanks.

Let the sludge phase concentrations of a component in Tank V-1 be represented by x1, x2, x3, x4, and x5. In this instance, the sludge phase concentration for a component was represented in terms of an average x, a standard error se, and a degree of freedom equal to 4.

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2.   Calculate the weighted average concentrations for both sludge and liquid for the entire V-tank waste

From Step 1, individual components in each V-tank have an average concentration with a standard error and a degree of freedom. The weighted average was calculated using the volumes, densities, and the solids concentration in the sludge. Each of these parameters has average values with their own standard errors and degrees of freedom. The final weighted averages for a given component in the entire V-tank is then expressed as an average value with a calculated standard error and a calculated degree of freedom. Appendix B of Tyson 2003 shows how to calculate the standard error and degrees of freedom (propagation of error).

3.   Individual averages, standard errors, and degrees of freedoms were calculated for both sludge and liquid in all of the other waste steams that are to be added to the V-tank consolidation and treatment system.

4.   Using the averages computed in Steps 2 and 3, calculate the overall composite waste stream weighted average, standard error, and degree of freedom for both phases. From these values, the 95% upper confidence limits for both liquid and sludge phase can be calculated as:

Composite V-Tanks Radionuclides @95%UCL						
Radionuclide	nCi/g	nCi/mL	nCi/g	Ci Sludge	Ci Liquid	Total Ci
Ag-108m	1.00E+00	3.58E-03	1.66E-01	7.50E-03	1.38E-04	7.64E-03
Am-241	9.16E+00	5.86E-04	1.49E+00	6.86E-02	2.25E-05	6.86E-02
Cm-242	3.87E-02	2.16E-05	6.32E-03	2.89E-04	8.29E-07	2.90E-04
Cm-243/244	2.40E+00	8.24E-05	3.91E-01	1.79E-02	3.17E-06	1.79E-02
Co-60	3.97E+02	3.59E-02	6.48E+01	2.97E+00	1.38E-03	2.97E+00
Cs-134	1.43E+00	3.23E-03	2.36E-01	1.07E-02	1.24E-04	1.08E-02
Cs-137	7.35E+03	1.09E+01	1.21E+03	5.50E+01	4.21E-01	5.55E+01
Eu-152	2.00E+01	1.45E-02	3.27E+00	1.50E-01	5.57E-04	1.50E-01
Eu-154	3.13E+01	4.84E-03	5.10E+00	2.34E-01	1.86E-04	2.34E-01
Eu-155	3.47E+00	1.24E-02	5.75E-01	2.59E-02	4.78E-04	2.64E-02
Ni-63	1.01E+03	2.60E-01	1.64E+02	7.53E+00	9.98E-03	7.54E+00
Np-237	3.17E-02	1.24E-04	5.27E-03	2.37E-04	4.77E-06	2.42E-04
Pu-238	1.53E+01	2.34E-03	2.50E+00	1.15E-01	9.01E-05	1.15E-01
Pu-239/240	8.56E+00	6.72E-04	1.40E+00	6.40E-02	2.58E-05	6.40E-02
Ra-226	2.42E-01	0.00E+00	3.94E-02	1.81E-03	0.00E+00	1.81E-03
Sr-90	1.55E+04	1.35E+01	2.55E+03	1.16E+02	5.19E-01	1.17E+02
U-233/234	5.17E+00	2.10E-02	8.60E-01	3.87E-02	8.07E-04	3.95E-02
U-235	1.66E-01	6.86E-04	2.76E-02	1.24E-03	2.64E-05	1.27E-03
U-238	9.01E-02	2.05E-04	1.49E-02	6.74E-04	7.88E-06	6.82E-04
Zn-65	1.89E-01	0.00E+00	3.09E-02	1.42E-03	0.00E+00	1.42E-03
Tritium	5.17E+01	2.52E+01	2.95E+01	3.87E-01	9.67E-01	1.35E+00
Th-228	4.83E-05	0.00E+00	7.87E-06	3.61E-07	0.00E+00	3.61E-07
Th-230	1.77E-05	0.00E+00	2.89E-06	1.33E-07	0.00E+00	1.33E-07
K-40	3.71E-04	0.00E+00	6.05E-05	2.78E-06	0.00E+00	2.78E-06

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III. Entrained Radionuclides and Loadings

III.a. Radionulide Entrainment in the Off-gas

To find the loadings for radionuclides, an entrainment function is needed. There is quite a bit of data available for entrainment of bubbling liquids from the DOE Handbook (DOE 1994). However, this data is not consistent in terms of dimensionless numbers so the curve to the far left was used corresponding to the small vapor velocity.

DOE-HDBK-3010-94

3.0 Liquids; Aqueous Solutions

+ Mishima
× Heger
△ Shor (.22 bar)
◇ Garner (foam)
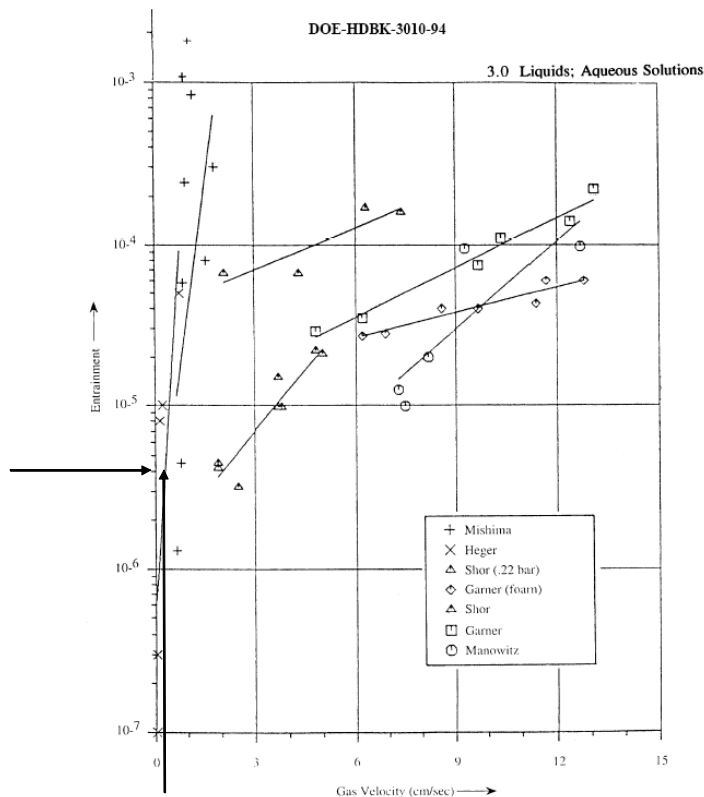△ Shor
▢ Garner
ⓞ Manowitz

Figure 3-2. Entrainment Data Obtained at Small Gas Velocity
(Borkowski, Bunz, and Schoeck May 1986)

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From Figure 3-2 and using their definition of entrainment (i.e., vapor mass velocities, G):

$$E := 4 \cdot 10^{-6} \qquad\qquad G_v := v_{tk} \cdot \rho_g \qquad\qquad G_{dplt} := E \cdot G_v$$

$$G_{dplt} = 1.28 \times 10^{-7} \frac{lb}{ft^2 \cdot min}$$

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This is the flux or mass velocity of water drops, for the radionuclide flux, multiply by the concentration, e.g.:

Gamma emitters ^{137}Cs and ^{60}Co

Concentrations based on total dissolved/undissolved

$$C_{Cs} := 1210 \frac{nCi}{gm} \qquad\qquad C_{Co} := 64.8 \frac{nCi}{gm}$$

$$G_{Cs} := G_{dplt} \cdot C_{Cs} \qquad\qquad G_{Cs} = 7.04 \times 10^{-2} \frac{nCi}{ft^2 \cdot min}$$

The rate would be for ^{137}Cs:

$$r_{Css} := G_{Cs} \cdot \frac{\pi}{4} \cdot D_{tk}^2 \qquad\qquad r_{Css} = 5.53 \times 10^0 \frac{nCi}{min}$$

$$G_{Co} := G_{dplt} \cdot C_{Co} \qquad\qquad G_{Co} = 3.77 \times 10^{-3} \frac{nCi}{ft^2 \cdot min}$$

The rate would be for ^{60}Co:

$$r_{Cos} := G_{Co} \cdot \frac{\pi}{4} \cdot D_{tk}^2 \qquad\qquad r_{Cos} = 2.96 \times 10^{-1} \frac{nCi}{min}$$

In addition to this entrainment, there is splashing from recirculation. A correlation for falling liquid is used for this (DOE 1994) and is correlated by the Archimedes number (Arch). It depends on several vapor/liquid parameters including the spill height z_s.

$$z_s := 34in$$

$$Arch := \frac{\rho_g^2 \cdot z_s^3 \cdot g}{\mu_L^2} \qquad\qquad Arch = 1.68 \times 10^6 \qquad\qquad Q_r := 100 \frac{gal}{min}$$

The airborne release fraction (ARF) is:

$$ARF := 8.9 \cdot 10^{-10} \cdot Arch^{0.55} \qquad\qquad ARF = 2.36 \times 10^{-6} \qquad\qquad$$ Based on DOE handbook and recommended by one of the principals, accurate to ~40% (Ballinger 1993, Ballinger 2005).

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This should correspond closely to recent testing for a dynamic situation (PNNL 2004) if spill heights are ratioed accordingly (e.g., $(z_2/z_1)^3$).

Account for deposition of the mean particle. Because of the uncertainties, guess the mean particle size low, i.e.:

$$D_m := 10\mu m \qquad\qquad \rho_p := 2\frac{kg}{L}$$

The settling velocity is (assuming the Cunningham-Stokes factor is 1):

$$v_{set} := \frac{\rho_p \cdot D_m^2 \cdot g}{18 \cdot \mu_g} \qquad\qquad v_{set} = 6.1 \times 10^{-3}\frac{m}{s}$$

The particles deposited are (Ballinger 1993):

$$d := 1 - \exp\left(\frac{-v_{set}}{v_{tk}}\right) \qquad\qquad d = 0.91 \qquad\qquad$$ Note: the distance to the filter and spill distance were equal in this equation and therefore cancelled out.

The emission rates for main γ emitters from splashing:

$$r_{CsR} := ARF \cdot Q_r \cdot C_{Cs} \cdot \rho_L \cdot (1-d) \qquad\qquad r_{CsR} = 1.02 \times 10^2\frac{nCi}{min}$$

$$r_{CoR} := ARF \cdot Q_r \cdot C_{Co} \cdot \rho_L \cdot (1-d) \qquad\qquad r_{CoR} = 5.47 \times 10^0\frac{nCi}{min}$$

The total emission rates:

$$r_{Cs} := r_{Css} + r_{CsR} \qquad\qquad r_{Cs} = 1.55 \times 10^5\frac{nCi}{day}$$

$$r_{Co} := r_{Cos} + r_{CoR} \qquad\qquad r_{Co} = 8.31 \times 10^3\frac{nCi}{day}$$

III.b. Radionuclide Loading based on Curie Content in HEPA

Case I, Scrubber. Assuming that there is a DF of 10000 from the scrubber, 50 for the 1st 6 inches (98%) and 20 for the 2nd 6 inches (95%) for the demister (Yapyuco 2005) and 100 for the HEPA (99%):

$$DF_s := 10000 \qquad\qquad DF_H := 100 \qquad\qquad DF_{dm} := 20 \cdot 50 \qquad\qquad W_{HEPA} := 20kg$$

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$$L_{Cs} := \frac{r_{Cs}}{DF_s \cdot W_{HEPA}} \qquad\qquad L_{Cs} = 7.76 \times 10^{-10} \frac{Ci}{kg \cdot day}$$

$$L_{Co} := \frac{r_{Co}}{DF_s \cdot W_{HEPA}} \qquad\qquad L_{Co} = 4.16 \times 10^{-11} \frac{Ci}{kg \cdot day}$$

$$t := 68\,day \qquad m_{Cs} := L_{Cs} \cdot t \qquad m_{Cs} = 5.28 \times 10^{-8} \frac{Ci}{kg}$$

$$m_{Co} := L_{Co} \cdot t \qquad m_{Co} = 2.83 \times 10^{-9} \frac{Ci}{kg}$$

Case II. For the case where there is no scrubber

$$L_{Cs} := \frac{r_{Cs}}{W_{HEPA}} \qquad\qquad L_{Cs} = 7.76 \times 10^{-6} \frac{Ci}{kg \cdot day}$$

$$L_{Co} := \frac{r_{Co}}{W_{HEPA}} \qquad\qquad L_{Co} = 4.16 \times 10^{-7} \frac{Ci}{kg \cdot day}$$

$$m_{Cs} := L_{Cs} \cdot t \qquad m_{Cs} = 5.28 \times 10^{-4} \frac{Ci}{kg}$$

$$m_{Co} := L_{Co} \cdot t \qquad m_{Co} = 2.83 \times 10^{-5} \frac{Ci}{kg}$$

Case III. The addition of a demister

$$L_{Cs} := \frac{r_{Cs}}{DF_{dm} \cdot W_{HEPA}} \qquad\qquad L_{Cs} = 7.76 \times 10^{-9} \frac{Ci}{kg \cdot day}$$

$$L_{Co} := \frac{r_{Co}}{DF_{dm} \cdot W_{HEPA}} \qquad\qquad L_{Co} = 4.16 \times 10^{-10} \frac{Ci}{kg \cdot day}$$

$$m_{Cs} := L_{Cs} \cdot t \qquad m_{Cs} = 5.28 \times 10^{-7} \frac{Ci}{kg}$$

$$m_{Co} := L_{Co} \cdot t \qquad m_{Co} = 2.83 \times 10^{-8} \frac{Ci}{kg}$$

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The highest energy particles were taken from the Chart of the Nuclides (Baum et al 2002) shown below.

Radiations	α MeV	β MeV	γ keV
Sr-90		0.546	
Cs-137		0.514	661.7
Ni-63		0.0669	
Co-60		0.318	1332.5
Pu-238/239/240	5.5		51.6

III.c. Approximate radiation fields

The doses are by the energy deposited:

Need quality factors for equivalent dose rate:

$$Q_\alpha := 20 \qquad\qquad Q_\beta := 1 \qquad\qquad Q_\gamma := 1$$

For ^{137}Cs there is the 661.7 keV γ photon and ^{60}Co 1.33 Mev:

$$E_{\gamma Cs} := 0.6617 \text{MeV} \qquad\qquad E_{\gamma Co} := 1.333 \text{MeV}$$

HEPA dose rate based on 20 kg HEPA not accounting for geometry assuming the HEPA absorbed dose is the same as for a person.

$$H_\gamma := \left(m_{Cs} \cdot E_{\gamma Cs} + m_{Co} \cdot E_{\gamma Co} \right) \cdot Q_\gamma \qquad\qquad H_\gamma = 8.25 \times 10^{-1} \frac{\text{mRad}}{\text{hr}}$$

IV.   Demister Mesh Design

The particle collection efficiency is a function of the specific surface area, a, the height of packing, z, and a specific efficiency for ribbons, cylinders and spheres, η_t (Perry et al 1984).

$$\eta = 1 - e^{\left(\frac{-2}{3} \cdot \pi \cdot a \cdot z \cdot \eta_t \right)}$$

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The specific efficiency is a function of the separation number:

$$n_s = \frac{K_m \cdot \rho_p \cdot D_p^2 \cdot v_o}{18 \cdot \mu \cdot D_o}$$

The Stokes-Cunningham Correction Factor, K_m, is
(http://courses.washington.edu/eh553a/Handout%201.pdf):

$$K_m = 1 + \frac{2.52 \cdot \lambda}{D_p}$$

Based on the large number of wires in the mesh, this is assumed to be 1.0 since the mean free path, λ, is not known and usually applies to only very small particles.

Perry's provides a plot of this. For wire (cylinders) it is shown below:

Particle Target Efficiency
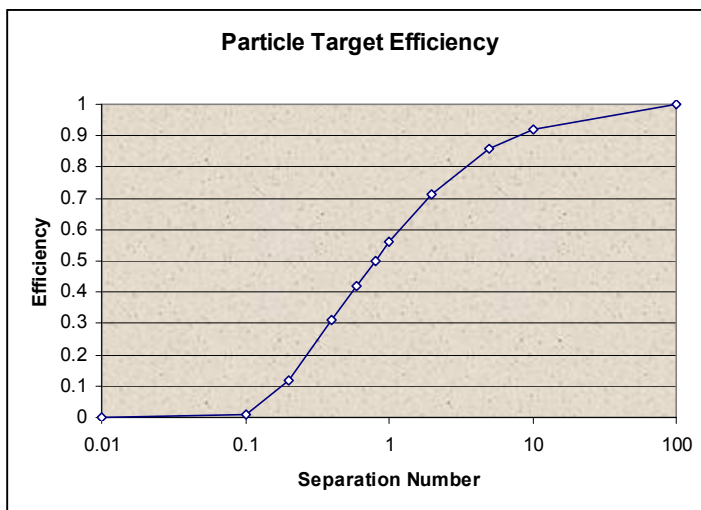
IV.1 Fabricated Unit by pushing wire into 6 inch basket

Because of the degrees of freedom (3), an example is provided using 0.5 mm steel wire.
1. Calculate the separation number with $K_m = 1$

2. Find efficiency from above plot (η_t).

3. Calculate the efficiency from the equation.

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Demister Data

Size of particle

Vent header diameter

$D_p := 5\mu m$

$D_v := 4in$

Stokes-Cunningham correction

Empty bed velocity

Wire diameter

$K_m := 1$

$v_o := \dfrac{4Q_s}{\pi \cdot D_v^2}$

$v_o = 7.64\dfrac{ft}{s}$

$D_o := 1mm$

Viscosity

Packing height

$\mu := 1.2 \cdot 10^{-5}\dfrac{lb}{ft \cdot s}$

$z := 12in$

Separation number:

$n_s := \dfrac{K_m \cdot \rho_p \cdot D_p^2 \cdot v_o}{18 \cdot \mu \cdot D_o}$

$n_s = 0.36$

From the plot above:

$\eta_t := 0.25$

$a := 50\dfrac{ft^2}{ft^3}$ Guess

$\eta := 1 - e^{\left(\frac{-2}{3} \cdot \pi \cdot a \cdot z \cdot \eta_t\right)}$

$\eta = 1$

Since $\eta > .999$, this works

The volume of the basket is:

$V_B := \dfrac{\pi}{4} \cdot D_v^2 \cdot z$

$V_B = 150.8in^3$

Estimate pressure loss

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$$\text{ftH2O} := 0.433 \text{psi} \qquad \text{inH2O} := \frac{\text{ftH2O}}{12} \qquad g_c := 9.8 \frac{\text{kg} \cdot \text{m}}{\text{kgf} \cdot \text{s}^2}$$

$$G_i := v_o \cdot \rho_g$$

$$\text{Re}_s := \frac{D_o \cdot G_i}{\mu} \qquad \text{Re}_s = 1.32 \times 10^2$$

Based on this Re $\qquad n := 1.3 \qquad$ and $\qquad f_m := 5$

$$\phi_s := .9 \qquad\qquad \text{guess for wire/cylinders}$$

For $\qquad a = 50 \dfrac{\text{ft}^2}{\text{ft}^3} \qquad A_w := a \cdot V_B \qquad A_w = 4.36 \text{ft}^2$

$$L_w := \frac{A_w}{\pi \cdot D_o} \qquad L_w = 4.23 \times 10^2 \text{ ft}$$

Estimate the void ratio, ε_i.

$$\varepsilon_i := 1 - \frac{\dfrac{\pi}{4} \cdot D_o^2 \cdot L_w}{V_B} \qquad \varepsilon_i = 0.96$$

Pressure drop analogue from a particle bed (Perry et al 1984). Note this is just an estimate based on a particle bed since a correlation is not available for this type of packing.

$$\Delta P := \rho_g \cdot \frac{4 \cdot f_m \cdot \left(1 - \varepsilon_i\right)^{3-n}}{\phi_s^{3-n} \cdot \varepsilon_i^3} \cdot \frac{z}{D_o} \cdot \frac{v_o^2}{2 \cdot g_c} \qquad \Delta P = 3.99 \times 10^{-1} \text{inH2O}$$

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IV.2 Fabricated Unit by using known stainless demister mesh into 12 inch basket (recommended)

Specify: $z := 12\text{in}$ Packing height $D_o := .006\text{in}$ Wire diameter

304 Stainless Steel, 19 1/2" x 100'

7.2 # Stainless Steel Woven Fabric Cloth Co.
5601 W. Slauson Avenue, Suite 260
Culver city, CA 90230-6598
Ben Yapyuco 310-258-9125 Fax: 310-258-9110

Separation number:

$$n_s := \frac{K_m \cdot \rho_p \cdot D_p^{\,2} \cdot v_o}{18 \cdot \mu \cdot D_o}$$ $n_s = 2.38$

From the plot above:

$$\eta_t := 0.7$$

Estimate specific surface area:

$$a := \frac{4}{D_o}$$ $a = 8 \times 10^3 \dfrac{\text{ft}^2}{\text{ft}^3}$

$$\eta := 1 - e^{\left(\frac{-2}{3} \cdot \pi \cdot a \cdot z \cdot \eta_t\right)}$$ $\eta = 1$

$$\rho_{mesh} := 7.2 \frac{\text{lb}}{\text{ft}^3}$$ $\rho_{steel} := 8.03 \dfrac{\text{kg}}{\text{L}}$

Estimate void fraction

$$\varepsilon_i := 1 - \frac{\rho_{mesh}}{\rho_{steel}}$$ $\varepsilon_i = 0.9856$

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$$\text{Re}_s := \frac{D_o \cdot G_i}{\mu}$$

$$\text{Re}_s = 2.01 \times 10^1$$

Based on this Re $\qquad$ $n := 1.14$ $\qquad$ and $\qquad$ $f_m := 6$

$$\Delta P := \rho_g \cdot \frac{4 \cdot f_m \cdot \left(1 - \varepsilon_i\right)^{3-n}}{\phi_s^{3-n} \cdot \varepsilon_i^3} \cdot \frac{z}{D_o} \cdot \frac{v_o^2}{2 \cdot g_c}$$

$$\Delta P = 0.251 \text{inH2C}$$

Corresponding close to vendor supplied value of 0.3 in H_2O and showing the particle bed correlation possibly predicts too low for wire.